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EFFECT OF PACKAGING MATERIAL AND STORAGE ENVIRONMENT ON THE PHYSIOCHEMICAL PROPERTIES OF PROCESSED TOMATO

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ABSTRACT: *The study evaluated the effect of glass, plastic and high-density polyethylene packaging materials on the physiochemical properties of processed tomato (Solanum lycopersicum L.) stored under two different environments for a period of three months (12 weeks). Two samples of Solanum lycopersicum L. of the tomato concentrate were packed in each of the above-mentioned packaging materials with one sample stored in a dark environment (dark cupboard) and the other stored where it receives sunlight. The result shows that the storage period, storage environments and packaging materials had effects on the parameters evaluated. While the MC%, TSS, Sugar-Acid ratio and pH of the stored samples increased across all packaging material and environments, TA, colour, lycopene and beta-carotene content of the samples decreased across all storage material and environment. The result also indicated that the quality of samples stored in the dark environment were better than those stored under sunlight.*

KEYWORDS: Tomato, Storage Environment, Physiochemical, lycopene, b-carotene.

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INTRODUCTION

The versatile culinary, pharmaceutical, and ornamental applications of (Salehi *et al., 2019;* Arah et al., 2015) coupled with its sensory appeal (Ponce-Valadez et al., 2016; Renard et al., 2013; Collins et al., 2022), has made tomato (*Solanum lycopersicum L*) one of the most popular vegetables worldwide. In 2021, over 189 million tons of fresh tomato fruits were produced worldwide, over 21 million tones produced from Africa with Nigeria producing over 3 million tons of it (FAOSTAT, 2021).

Tomatoes contain in abundance active compounds (phytochemicals) essential for human health (Dladla & Workneh, 2023). These nutritional phytochemicals include phenolic compounds (phenolic acids and flavonoids), glycoalkaloids (tomatine, lutein, neoxanthin, violaxanthin, a-cryptoxanthin, zeaxanthin and b-cryptoxanthin) and carotenoids (lycopene, b-carotene, g-carotene, z-carotene, phytoene, phytofluene, cyclolycopene and neurosporene) *(*Khachik et al., *2002).* It is responsible for the colour of riped tomatoes as well as the numerous health benefits of the fruit (Salehi *et al.,* 2019*;* Clinton 1998). Khachik et al. (*2002)* reported that the antioxidant effects of lycopene is 10 times higher than vitamin E. The presence of lycopene is responsible for the many health related benefits of tomatoes. Research has shown that a high level of lycopene in our body can help to fight against cancer (Gann et al., 1999; Assar et al., 2016; Yuan et al., 2004) and used as biomarker for cardiovascular diseases (Wang et al., 2018; Petyaev, 2016), osteoporosis (Rao et al., 2007; Costa-Rodrigues et al., 2018) and cognitive function (Wang et al., 2018). The health benefits and harmful effect of tomato consumption to human health is summarized in Figure 1.

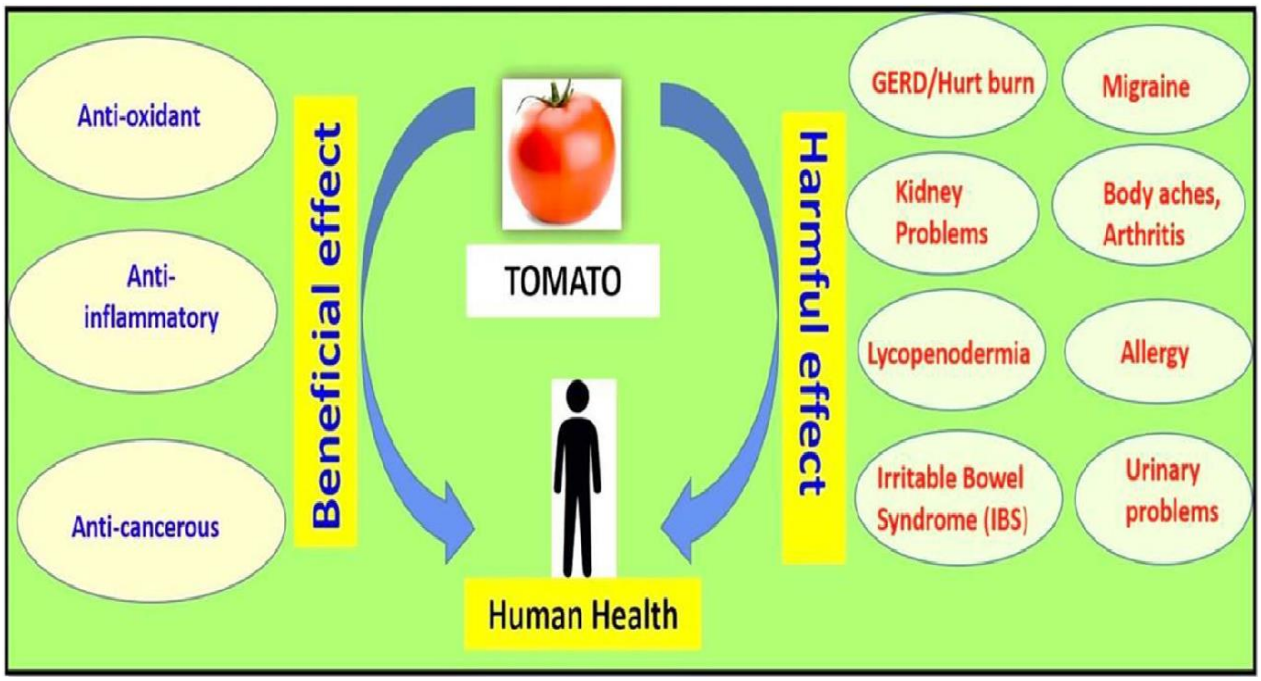

Figure 1: Beneficial and harmful effects of tomato on human health (Khachik et al., 2002).

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Regardless of the huge production capacity and numerous health benefits associated with tomatoes, it is still largely unprofitable especially for a developing and agrarian nation like Nigeria due to post-harvest losses. Post-harvest losses can either be an on-farm (improper harvesting stages, excessive field heat, improper harvesting containers, poor farm sanitation and improper packaging materials) or off-farm (lack of access roads, inappropriate transportation system, lack of processing factories and lack of reliable market information) categories. While both categories are major sources of concern, the use of technology, processing, right packaging materials and proper storage conditions can drastically reduce the off-farm post-harvest losses. Thus, this study seeks to evaluate the effect of three commonly used packaging materials (glass, plastic bottle (PET) and high-density polyethylene bag (HDPE)) and two storage environments (dark cupboard and sunlight) affect the physiochemical properties of concentrated tomato.

MATERIALS AND METHODOLOGY

Preparation of the Materials

The material used for this work is raw tomato fruit. Ripe tomato fruits were obtained from Eke Market Afikpo in Ebonyi State. The fruits were carefully taken to the Department of Food Technology, Akanu Ibiam Federal Polytechnic Unwana where it was processed. The glass jars and plastic bottles were thoroughly washed and rinsed with clean water. The glass jar was oven dried for 24 hours in a kinetic oven at 105℃ while the plastic bottles were allowed to dry by facing down for 72hrs.

Processing of the Fruit

Fresh and healthy tomatoes bought from the local market and measuring 2kg were sorted, cleaned and graded based on ripeness and soundness. The resultant seeds were blanched for 15s at 80℃ before milling. The tomato was sieved to separate the pomace (seed and peel) from the pulp. The pulp was concentrated by allowing it to stand on the filter until 70% of the water is lost. The left-over pulp was mixed with lime and heated for 45 minutes at 80^{o}C with constant stirring. The product was allowed to cool for 10 minutes before being packaged into a well labelled container. Those labelled GLS, PLS and NLS were stored in an environment where they were exposed to direct access to light while samples GDS, PDS and NDS were stored in a dark cupboard.

ANALYSIS

The properties (physical and chemical) of the stored samples were analyzed immediately after processing (week 0 or control) and repeated fortnightly for a period of 12 weeks (about 3 months). The parameters analyzed include moisture content, total soluble solid, titratable acids, pH, sugar acid ratio, lycopene content, total carotene content and total colour difference.

Moisture Content (MC): The moisture content (MC%) was calculated using the equation as described by Nnam *et al.*, (2021):

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$$Moisture\ content\ (\%) = \frac{W_1 - W_2}{W_1} \times 100 \qquad (1)$$

where W1 = original weight of the sample before drying; W2 = weight of the sample after drying.

Total Soluble Solids (TSS): TSS was determined using a hand refractometer.

Titratable Acidity (TA): The titratable acidity of the fruit samples was determined as described by Żyżelewicz and Oracz (2022) by titrating 25 mL of the sample tomato juice with 0.1 mol/L of sodium hydroxide (NaOH) and expressed as percentage citric acid.

pH Value: The pH of the tomatoes was measured using a method described by Tigist *et al*. (2013) using a glass electrode pH meter.

Sugar/Acidity Ratio (SAR): To determine the sugar to acid ratio, the sugar (TSS) concentration in °Brix was divided by percentage acid: The sugar acid ratio = °Brix value/Percentage acid.

Determination of Lycopene Content of the Samples

The lycopene concentration was determined as described by Ye *et al*. (2018). It was quantified using 503nm of the spectrophotometer calculated as µg of lycopene /g of the sample taken.

$$\frac{\mu g}{g} = \left(\frac{Abs \times Vol \times 10^4}{\varepsilon \times Weight\ of\ sample}\right) \qquad (2)$$

where Ɛ is a constant = 2505; *Abs= absorbance reading.*

β **−Carotene Content:** It was determined following the same procedure and calculation as lycopene but was quantified using 450nm of the spectrophotometer, *where $\mathcal{E}$ = constant = 2505; vol = volume of n-hexane; Abs = absorbance reading*.

Total Colour Difference

Colour characteristics of the tomato concentrate samples were determined by using colour charts for matching and describing colour in tomatoes by the panelists as described by Tigist et al. (2013). A rating scale of 1-9 of the colour lightness was used to evaluate colour change during storage period.

RESULTS

The study recorded an increase of MC from 83.73% obtained immediately after processing to 85.7%, 86.3% and 89.85% for high density polyethylene, PET and glass respectively in Week 12. Table 1 also shows that storage environment affected the moisture content of the stored samples with the samples having the highest percentages (%). While NDS, PDS and GDS had 85.7%, 86.3% and 89.85% respectively in week 12, NLS, PLS and GLS had 84.23%, 84.9% and 87.8%

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Table 1: Effect packaging materials and storage environment on moisture content

Samples	Weeks						
	0	2	4	6	8	10	12
GDS	83.73	84.40	84.82	86.24	87.95	88.14	89.85
GLS	83.73	83.92[c]	85.23	86.01[c]	86.63	87.05	87.80
PDS	83.73	83.89	84.05	85.06[a]	85.55	85.96	86.30
PLS	83.73	83.81	83.93	84.04	84.32	84.68	84.90
NDS	83.73	84.00	84.02	84.15	84.66	85.24	85.70
NLS	83.73	83.88	83.97	84.03	84.11	84.21	84.23

Values with the same superscript in the same column are significantly different at p<0.05. The values are means of duplicate samples.

Table 2: Effect of packaging materials and storage environment on total soluble solid (^{0}brix)

Samples	Weeks						
	Control	2	4	6	8	10	12
GDS	15.25	15.35	15.65	15.81	15.98	16.01	16.03
GLS	15.25	15.55	15.78	15.95	16.15	16.55	16.75
PDS	15.25	15.05	15.05	15.05	15.05	15.05	17.01
PLS	15.25	15.05	15.05	15.05	15.05	13.25	17.34
NDS	15.25	15.88	16.25	16.80	17.45	18.05	18.67
NLS	15.25	16.53	17.05	17.63	18.03	18.51	19.00

Values with the same superscript in the same column are significantly different at p<0.05. The values are means of duplicate samples.

Table 3: Effect of packaging materials and storage environment on TA (%)

Samples	Weeks						
	0	2	4	6	8	10	12
GDS	0.54	0.50	0.43	0.40	0.38	0.36	0.34
GLS	0.54	0.48	0.45	0.41	0.37	0.33	0.30
PDS	0.54	0.43	0.39	0.35	0.30	0.28	0.27
PLS	0.54	0.44	0.39	0.31	0.29	0.24	0.22
NDS	0.54	0.43	0.38	0.30	0.27	0.23	0.21
NLS	0.54	0.45	0.37	0.35	0.29	0.24	0.18

Values with the same superscript in the same column are significantly different at p<0.05. The values are means of duplicate samples.

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Table 4: Effect of packaging materials and storage environment on pH of the samples

Samples	Weeks						
	0	2	4	6	8	10	12
GDS	3.86	3.93	4.00	4.02	4.18	4.21	4.22
GLS	3.86	3.96	3.99	4.02	4.36	4.37	4.41
PDS	3.86	3.96	4.00	4.04	4.10	4.18	4.22
PLS	3.86	3.91	3.99	4.01	4.24	4.25	4.24
NDS	3.86	3.92	3.97	4.09	4.18	4.21	4.23
NLS	3.86	3.91	3.98	4.11	4.20	4.22	4.31

Values with the same superscript in the same column are significantly different at p<0.05. The values are means of duplicate samples.

Table 5: Effect of packaging materials and storage environment on Sugar-Acid Ratio (%)

Samples	Weeks						
	0	2	4	6	8	10	12
GDS	97.67	115.41	128.01	142.82	160.93	171.24	189.55
GLS	97.67	139.78	169.32	187.77	201.52	238.10	245.60
PDS	97.67	127.55	144.08	184.42	198.86	207.12	225.77
PLS	97.67	121.88	137.72	168.10	186.05	194.54	201.75
NDS	97.67	124.35	140.44	177.57	198.03	207.21	220.10
NLS	97.67	130.33	174.50	181.57	194.58	211.20	236.95

Values with the same superscript in the same column are significantly different at p<0.05. The values are means of duplicate samples.

Table 6: Effect of packaging materials and storage environment on lycopene content (mg/100g)

Samples	Weeks						
	0	2	4	6	8	10	12
GDS	4.23	4.15	4.08	4.03	3.95	3.78	3.66
GLS	4.23	4.01	3.92	3.90	3.84	3.75	3.45
PDS	4.23	3.77	3.61	3.42	3.15	3.01	2.88
PLS	4.23	3.55	3.21	2.97	2.73	2.68	2.11
NDS	4.23	4.10	4.00	3.08	3.27	3.51	3.79
NLS	4.23	3.65	3.89	2.96	2.81	2.73	2.67

Values with the same superscript in the same column are significantly different at p<0.05. The values are means of duplicate samples.

Table 7: Effect of packaging materials and storage environment on total carotene (mg/100g)

Samples	Weeks						
	0	2	4	6	8	10	12
GDS	4.81	4.78	4.61	4.53	3.43	3.39	3.38
GLS	4.81	4.63	4.03	4.02	3.01	2.96	3.35
PDS	4.81	4.55	4.41	4.40	3.40	3.39	3.34

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PLS	4.81	4.17	3.44	3.43	3.34	3.30	3.00
NDS	4.81	4.51	4.43	4.40	3.40	3.36	3.31
NLS	4.81	4.17	4.11	4.10	3.03	2.95	2.91

Values with the same superscript in the same column are significantly different at p<0.05. The values are means of duplicate samples.

Table 8: Effect of packaging materials and storage environment on total colour difference

Samples	**Weeks**						
	0	**2**	**4**	**6**	**8**	**10**	**12**
GDS	3.24	3.34	4.01	5.32a	7.47	8.45	11.35
GLS	3.24	4.57	6.88	8.96	11.16	13.35	15.14
PDS	3.24	3.78	4.33	6.26	8.58	10.67	13.47
PLS	3.24	5.22	7.39	9.66	10.56	13.43	16.25
NDS	3.24	5.45	7.71	9.88	11.00	12.56	14.68
NLS	3.24	6.71	8.56	10.86	12.66	15.11	18.98

Values with the same super script in the same column are significantly different at p<0.05. The values are means of duplicate samples.

DISCUSSION

Moisture Content of Concentrates

The moisture content (MC%) of tomato concentrates samples was significantly affected by both the packaging material and storage condition progressively for the 12 weeks storage period (Table 1). The study recorded an increase of MC from 83.7% obtained immediately after processing to 85.7%, 86.3% and 89.85% for high density polyethylene, PET and glass respectively in Week 12. Table 1 also shows that storage environment affected the moisture content of the stored samples with the samples having the highest percentages (%). While NDS, PDS and GDS had 85.7%, 86.3% and 89.85% respectively in Week 12, NLS, PLS and GLS had 84.23%, 84.9% and 87.8% respectively in Week 12. MC impact in food is high as it affects the shelf-life, texture, flavor profiles, quality and safety as well as the kinetic of lipid oxidation, microbial growth, and browning (Sand, 2021). The difference observed in terms of the packaging materials can be attributed to the Water vapour transmission rate, permeability and diffusion coefficient (Hülsmann & Wallner, 2017) of the various packaging materials which has been shown to be lowest in glass and highest in PET (Sandra et al., 2022), although the diffusion rate of PET is lower than HDPE (Hülsmann & Wallner, 2017). The storage environment effect could be attributed to the temperature and relative humidity of the environment which aided evaporation (Nkolisa et al., 2019; Dladla & Workneh, 2023). The results obtained in this study agree with the result obtained by Shishir *et al.* (2017) for stored fruit, and the result reported by Sandra *et al.* (2022) for glass PET and high-density polyethylene.

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Total Soluble Solids (TSS)

TSS is a qualitative parameter that affects the safety and hedonic properties of fruits (Mauer & Bradley, 2017). It qualitatively measures the dissolved sugar (glucose, sucrose and fructose) (Chen et al., 2020), acid (citrate and malate) (Annelisa et al., 2021), and other minor components such as soluble pectin, ascorbic acids and amino (Wu et al., 2022) in the product. This helps it to indicate the level of sweetness of food (Rodríguez-Ortega et al., 2019). Table 2 shows a gradual increase in TSS value for samples stored in glass [15.25-16.75(^{0}brix) for GLS; 15.25-16.03(^{0}brix) for GDS] and rapid increase for PET [15.25-17.34(^{0}brix) for PLS; 15.25-17.01(^{0}brix) for PDS] and HDPE samples [15.25-19.00(^{0}brix) for NLS; 15.25-18.67(^{0}brix) for NDS]. Furthermore, it can be seen from the result that samples stored in the light increased more than those stored in the dark. The difference in the rate of TSS increase can be attributed to the level of CO_2 production by the packaging material which slows physiological processes (Sandra *et al.*, 2022). Nath et al. (2012) observed that non-perforated packaging material with the highest level of CO2 has the slowest physiological process, hence the value of TSS in glass and others. The TSS increase in the samples can be attributed to starch hydrolysis and transformation of unbranched polygalacturonates (Hernández-Urbiola, Margarita et al., 2011). Nath et al.'s (2012) result of 10-12.8 (^{0}brix) agrees with this study's observation. This was further corroborated by Attanayake et al. (2019). However, Famurewa et al. (2013) reported a constant TSS throughout the storage period (6 weeks). From the result, it can be inferred that there is high risk of fructose related concerns (Rizkalla et al., 2010; Nakagawa et al., 2005; Aeberli et al., 2007; Taskinen et al., 2019; Parks et al., 2008) when tomatoes are stored in HDPE for a long period.

Titratable Acid (TA) and pH

In food analysis, TA and pH can be used in acidity measurement (Nielsen, 2021). Although pH impacts flavour and taste of food by giving an indication of its susceptibility to microbial growth (Aderibibge et al., 2018), TA is a better indicator of the effect of organic acid on food flavour because it gives a better indication of the level of food acid ionization and their impacts (Nielsen, 2021; Owusu et al., 2012). TA showed a progressive decrease during storage. It decreased from 0.54 in week 0 to 0.34 for GDS, 0.27 for PDS and 0.21 for NDS. These values are higher than the samples under sunlight, i.e., GLS (0.30), PLS (0.22) and NLS (0.18). The decrease in TA for all samples can be attributed to the utilisation of organic acid for metabolism during storage (Tigist & Wakgari 2016). The consumption of organic acid aids fruit respiration (Abiso et al., 2015; Albertiniet al., 2006). This causes the organic acids to decrease with maturity or increasing storage duration with a corresponding increase in fruit pH (Moneruzzamanet al., 2009). This is also supported by this work as Table 4 shows an increase in pH value as storage duration increases. At week 0, the pH of the samples was 4.11. This value steadily increased to 4.41 for GLS, 4.24 for PLS, 4.27 for NLS, 4.31 for GDS, 4.22 for PDS and 4.23 for NDS. The results show that the storage of tomato concentrate under sunlight will encourage microbial (Kim et al., 2019). The study results for both TA and pH agree with Al-Dairi et al. (2021) that reported a progressive decrease and increase in the value of TA and pH respectively of stored tomatoes. The result is further supported by Habib et al. (2009) and Abiso et al. (2015).

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Sugar-Acid Ratio

The packaging materials and the storage environment significantly impacted on the sugar-acid ratio of tomatoes during storage (Table 5). The sugar-acid ratio ranged from 97.67-189.55 for GDS, 97.67-245.60% for GLS, 97.67-225.77% for PDK, 97.67-201.75% for PLS, 97.67-220.10% for NDS and 97.67-236.95% for NLS. The maximum acidity sugar ratio was recorded for GLS while PLS had the minimum value. It was observed that samples GLS and NLS increased more than samples GDS and NDS, but the reverse was observed for samples PLS and PDS with PDS increasing more than PLS. The increase in sugar acid ratio of the samples can be attributed to starch hydrolysis into water soluble sugars such as sucrose, fructose, glucose, etc during storage or maturity (Habib et al., 2009). Given that the food acidity gradually decreased with a corresponding increase in the TSS and sugar values, the storage intrinsically imparted flavour on the food (Kulkarni & Aradhya, 2005).

lycopene Concentration

The lycopene concentration of sample GDS decreased from 4.23 in week 0 to 4.15, 4.08, 4.03, 3.95, 3.78 and 3.66 for weeks 2, 4, 6, 8, 10 and 12 respectively. GLS also decreased from 4.23 to 4.01, 3.92, 3.90, 3.84, 3.75 and 3.45 for weeks 2, 4, 6, 8, 10 and 12 respectively (Table 6). Considering the samples stored in PET, a decrease in the value of lycopene was also observed for both storage conditions (Table 4). PDS decreased from 4.23 to 3.77, 3.61, 3.42, 3.15, 3.01 and 2.88 for weeks 2, 4, 6, 8, 10 and 12 while PLS had a lower value compared to PDS. The value of PLS was 3.55, 3.21, 2.97, 2.73, 2.68 and 2.11 from 4.23 over 12 weeks storage period. NDS and NLS samples showed the same trend with NDS decreasing from 4.23 to 3.79 and NLS to 2.67 over 12 weeks storage period. The result of this study supports an earlier result of Li et al. (2018). The authors observed that the lycopene decreased progressively when stored for 12 weeks and under varying temperatures (10, 25 and 37 degrees). Nkolisa et al. (2019) and Al-Dairi et al. (2021) reported an increase in lycopene when fresh tomatoes were stored for 20 days between 19 and 32℃ and 12 days for (10 and 22)℃ respectively. The difference in the results could be attributed to the processing of the tomato samples before storage as it had earlier been reported that processing as well as the method of processing affect the lycopene content of tomato (Shi et al., 2000; Li H et al., 2018).

Another factor that could have caused the difference in results is the type of cultivar used. Although we did not consider the cultivar used, Martínez-Hernández (2016) observed that the cultivar determines the final lycopene content of stored tomatoes as the lycopene in some cultivars decreases faster than the others under storage. However, all the cited works, including this study, agree that temperature (storage environment) affects the lycopene concentration in tomatoes. Higher temperature (represented by sunlight in our study) reduces the lycopene in tomatoes. The decrease of lycopene after processing has been attributed to isomerisation and oxidation of lycopene which results in dehydration of this bioactive compound and reduces its availability (Martínez-Hernández et al., 2016; Willcox et al., 2003).

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β-carotene Content

The decrease observed in the carotene content of the stored tomato concentrate samples is shown in Table 7. Although the concentration of total carotene decreased in all samples, samples stored in glass had the highest β-carotene content value while samples stored in HDPE had the lowest. Again, samples stored in the dark showed higher values of carotene content for all packaging materials indicating that the storage environment significantly affected the parameter as sunlight causes fading of the food pigment exposed to them while temperature causes degradation of the chemical component (Trifiro *et al.*, 1998). The result of this study agrees with Martínez-Hernández et al. (2016), Capanoglu et al. (2008), Georgé et al. (2011), and Xu et al. (2018). The cited studies recorded a decrease in β-carotene content but attributed the decrease to the effect of processing and technology. However, D'Evoli et al. (2013) observed a steady decrease (1.00-0.75; 1.00-0.93; 1.07-1.01; 1.38-1.15mg/100mg) in stored Cherry tomatoes.

Total Colour Difference

The impact of the storage and packaging materials on the samples' colour (physical characteristic) is evident in Table 8 as expressed in the energy change (ΔE) value. It was observed that there was a significant change ($P<0.05$) in ΔE for all the samples throughout the period of storage period. ΔE decayed or decreased for all samples but was most significant for the samples stored under sunlight with NLS sample having the most decay. This can be attributed to the heat radiation properties of black bodies (black coloured HDPE) (Awad et al., 2019). The result of this study correlates with the investigation of Rhim and Hong (2011) which showed that an increase in temperature caused the colour of red pepper to become brighter (decay). Similar investigations on the influence of temperature and storage environment on fruits were carried out by Ahmed et al. (2002) and Lee (2000), and a similar report (decay in ΔE as temperature increases) was reported. Pathare et al. (2013) noted that colour is an important parameter in identifying the characteristic flavour of foods and that altering typical colour may render the identification of flavour less precise.

CONCLUSION

The effect of three packaging materials (glass, PET and HDPE) and two storage environments (cupboard and sunlight) on the physical (colour and MC) and chemical properties (TSS, TA, pH, sugar acid ratio, lycopene and β-carotene content) of concentrated tomato. The tomato concentrate was produced by concentrating tomato pulp using filtration and evaporation to ensure minimum heat treatment. The result of the study showed a significant effect of the parameters on the properties measured. The result showed that the effect was less on samples stored in the dark than for those under sunlight. The glass packaging material showed a slower loss of the bioactive components (lycopene and β-carotene) which are the major sources of the health benefits of the fruit. Therefore, for tomato concentrate to retain most of its qualities while in storage, it should be packaged in a glass container and stored in the dark, most preferably in a dark cupboard.

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